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DRAINAGE *of* EARTH ROADS

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An Engineering Experiment Station was established at the University of Illinois by action of the Board of Trustees, December 8, 1903. It is the purpose of the Station to carry on investigations along various lines of engineering and to study problems of importance to professional engineers and to manufacturing, railway, constructional, and industrial interests of the state. The laboratories of the College of Engineering are being equipped with additional apparatus and facilities to further such research work. It is believed that this experimental work will result in contributions of value to engineering science and that the presence of such investigations will give inspiration to students and add efficiency to the College of Engineering.

The publications of the Station consist of Bulletins which contain the results of original investigations, and of Circulars which present subjects believed to be of value to those addressed although the matter itself may not be entirely new.

This Circular is presented to assist the movement for the improvement of the wagon roads, and it is hoped that it may be helpful to those having in charge the highways of the state.

All correspondence concerning the work of the Station should be addressed to the Engineering Experiment Station, Urbana, Illinois.

DRAINAGE OF EARTH ROADS.

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Drainage is the most important matter to be considered in either the construction or the maintenance of any form of road, since no road, whether earth, gravel or broken stone, can long remain good without it. Drainage alone will often change a bad earth road to a good one, while the best stone road may be destroyed by the absence of proper drainage. Water is the natural enemy of earth roads, for mixed with earth it makes mud, and mud makes bad going. The rain or snow softens the earth; the horses' feet and the wagon wheels mix and knead it; and soon the road becomes impassable mud, which the frost finally freezes, and the second state of the road is worse than the first—for a time at least. Further, if the water is allowed to course down the middle of the road it will wash away the earth, and leave gullies in the surface that must be laboriously filled up by traffic or repairs. No road, however well made otherwise, can endure if water collects or remains on it. Prompt and thorough drainage is a vital essential in all road construction, and particularly so for earth roads.

A perfectly drained road will have three systems of drainage, each of which must receive special attention if the best results are to be obtained. This is true whether the trackway be iron, broken stone, gravel, or earth; and it is emphatically true of earth. These three systems are (1) underdrainage, (2) side ditches, and (3) surface drainage.

1. Underdrainage.

3 Any soil in which the standing water in the ground comes at any season of the year within 4 or 5 feet of the surface will be benefited by drainage; that is, if the soil does not have a natural underdrainage, it will be improved for road purposes by artificial subsurface drainage. It is the universal observation that roads in low places which are underdrained dry out sooner than undrained roads on high land. Underdrained roads never get as bad

as do those not so drained. Underdrainage without grading is better than grading without drainage; and, in general, it may be said that there is no way in which road taxes can be spent to better advantage than in subsurface drainage. Underdrainage is the very best preparation for a gravel or stone road. Gravel or broken stone placed upon an undrained foundation is almost sure to sink (perhaps slowly, but none the less surely), whatever its thickness; whereas a thinner layer upon a drained road-bed will give much better service. Underdrained roads without gravel are better than graveled roads without underdrainage.

Objects of Underdrainage.

Many persons seem to think that the sole object of underdrainage is to remove the surface water, but this is only a small part of the advantages of the underdrainage of roads. There are three distinct objects to be sought by the underdrainage of a wagon road, viz.: (1) to lower the water level in the soil; (2) to aid in drying the ground quickly after a freeze; and (3) to cut off the underflow.

1. To Lower the Water Level. When rain water falls upon the surface of the ground it sinks into the soil, and continues to flow downward until it reaches soil that is saturated, that is, it flows vertically downward until it reaches the surface of what may be called the underground lake. The most important object of underdrainage is to lower the level of this underground lake. The action of the sun and the breeze will finally dry the surface of the road; but if the foundation is soft and spongy, the wheels will wear ruts and the horses' feet will make depressions between the ruts. The first shower fills these depressions with water, and the road is soon a mass of mud. A good road can not be maintained without a good foundation; and an undrained soil is a poor foundation, but a dry soil can support almost any load. The lowering of the surface of saturation not only improved the road by keeping the surface comparatively dry, but also prevents, or greatly reduces, the destructive effect of frost. The injurious effect of frost is caused entirely by the presence of water, and the more water there is in the road-bed the greater the injury to the road. The water expands on freezing, the surface of the road is upheaved, and the soil is made porous; when thawing takes place,

the ground is left honeycombed and spongy, ready to settle and sink, and under traffic the road "breaks up." If the road is kept dry, it will not break up. Underdrainage can not prevent the surface of the road from becoming saturated with water during a rain, but it is the best means of removing the surplus water, thus drying the surface and preventing the subsequent heaving by frost.

That frost is harmless where there is no moisture, is shown on a large scale in the semi-arid regions west of the Mississippi River. The ground there is normally so dry that during the winter when it is frozen, cracks form half an inch or more wide, owing to the drying and consequent contraction of the soil, which shows that there is no expansion by the freezing of water in the soil; and therefore there is no heaving or disturbance by frost. In this region houses are often built on the very surface of the ground, and no trouble is ever experienced by the action of frost. But in Illinois the surface soil is frequently saturated; and therefore it is necessary to underdrain to prevent the heaving of the frost, and the consequent "breaking up" of the roads.

2. **To Aid in Drying the Ground Quickly After a Freeze.** When the frost comes out of the ground in the spring, the thawing is quite as much from the bottom as from the top. If the land is underdrained, the water when released by thawing from below will be immediately carried away, which is particularly important in road drainage, since the foundation will then remain solid and the road itself will not be cut up. Underdrainage will usually prevent the "bottom dropping out" when the frost goes out of the ground. This effect of underdrainage is much more important than many seem to think, but a little observation will show its value.

3. **To Cut Off the Underflow.** A third, and sometimes a very important, object of subdrainage is to remove what may be called the underflow. In some places where the ground is comparatively dry when it freezes in the fall, it will be very wet in the spring when the frost comes out—surprisingly so considering its dryness before freezing. The explanation is that after the ground freezes, water rises slowly in the soil by the hydrostatic pressure of the water in higher places; and if it is not drawn off by underdrainage, it saturates the subsoil and rises as the frost goes out, so that the ground which was comparatively dry when it froze is practically saturated when it thaws.

The Method of Underdrainage.

The Tile. The best and cheapest method of securing underdrainage is to lay a line of ~~porous or~~ farm tile 3 or 4 feet deep on one or both sides of the roadway. The ordinary farm tile is entirely satisfactory for road drainage. It should be uniformly burned, straight, round in cross section, smooth inside, and have the ends cut off square. Tile may be had from 3 to 30 inches in diameter. The smaller sizes are usually a foot long, and the larger sizes are 2 or 2½ feet long, but usually the former. The cost of tile free on board cars at almost any railroad station in Illinois is about as given in Table 1, although the prices may be a little higher or a little lower, depending upon the demand at the factory or upon the freight rate. Y's for connections can be had at most factories, but they cost four or five times as much as an ordinary tile. With patience and a little experience ordinary tile can be cut to make fairly good connections.

Before the introduction of tile for agricultural drainage, it was customary to secure underdrainage by digging a trench and depositing in the bottom of it logs or bundles of brush, or a layer of broken stone; or a channel for the water was formed by setting a line of stones on each side of the trench and joining the two with a third line resting on these two. Apparently it is still the practice in some localities to use such substitutes for ordinary drain tile. Tiles are better, since they are more easily laid and are less liable to get clogged. Tiles are cheaper in first cost, even when shipped considerable distances by rail, than any reasonably good substitute, and the drains are much more durable.

Tiles are laid simply with their ends in contact, care being taken to turn them until the ends fit reasonably close. In some localities there is apparently fear that the tile will become stopped by fine particles of soil entering at the joints, and consequently it is specified that the joint shall be covered with tarred paper or something of the sort; but in the Mississippi Valley, where immense quantities of tile have been laid, no such difficulty has been encountered. With a very slight fall or even no fall at all, tiles will keep clean, if a free outlet is provided and if they are not obstructed by roots of trees—particularly willow.

In some localities it is apparently customary to use collars around the ends of the tile to keep them in line. If the bottom of

TABLE I.

Cost and Weight of Drain Tile.

SIZE	Price per 1,000 feet	Weight per foot	Average Car Load		Pricee of Connections
			No. pieces	Rods	
4-inch tile............	$ 15.00	6 lbs.	6,500	390	$ .10
5 " '	21.00	8 "	5,000	300	.12
6 " "	27.00	11 "	4,000	240	.14
7 " "	36.00	14 "	3,000	180	.15
8 " "	48.00	18 "	1,200	144	.25
10 " "	66.00	25 "	800	96	.35
12 " "	95.00	33 "	500	60	.50
14 " "	150.00	43 "	400	48	.60
15 " "	165.00	50 "	300	36	.70
16 " "	190.00	53 "	250	30	.80
18 " "	265.00	70 "	200	24	1.00
20 " "	335.00	83 "	166	20	1.25
22 " "	400.00	100 "	160	19	1.50
24 " "	450.00	112 "	150	18	2.00
30 " "	750.00	192 "	65	10	3 00

the trench is made but little wider than the diameter of the tile, or if a groove is scooped out in the bottom of the trench to fit the tile, no difficulty need be apprehended from this source.

The Size of Tile. The following formula is sometimes employed to determine the amount of water removed by a tile; but the formula is only approximate, and results obtained with it are only mathematical guesses, since we can not know with any certainty the maximum rate of rainfall, the duration of the maximum rate, the permeability of the soil, the amount of water retained by the soil, the effect of surface water flowing onto the road from higher ground, the area to be drained, etc. The formula is useful only in a locality where there is no local experience with tile; and its chief value consists in showing the relation between capacity and grade, and the effect of a variation in the diameter of the tile.

The formula is:

$$A = 1.9 \sqrt{\frac{f\, d^5}{l}}$$

in which **A** is the number of acres for which a tile having **a** diameter of **d** inches and a fall of **f** feet in a length of **l** feet will remove 1 inch in depth of water in 24 hours.

The object of underdraining a road is to prevent the plane of saturation from rising so near the surface as to soften the foundation of the road even during a wet time, and therefore the provision for underdrainage should be liberal; but what will be ade-

quate in any particular case depends upon the amount of traffic, the local conditions, the soil, etc. The best practice in agricultural drainage provides for the removal of 0.5 to 1 inch of water per day; but since the side ditches will assist in removing rain water from the road, it is probable that a provision for the removal of half an inch per day is sufficient for the underdrainage of a road. If there is an underflow of water from higher ground, or if the ground is "springy," then the ordinary provisions for underdrainage should be increased.

It is not wise to lay a smaller tile than a 4-inch one, and probably not smaller than a 5-inch. Tiles can not be laid in exact line, and any tilting up of one end reduces the cross section. Again, if there is a sag in the line equal to the inside diameter, the tile will shortly become entirely stopped by the deposit of silt in the depression.

It is sometimes wiser to lay a larger tile than to increase the fall. Again, it may be better to lay a large tile near the surface with smaller fall than to lay small tile deeper with a greater fall. Ordinarily, the deeper the tile the better the drainage, although 3½ or 4 feet deep is usually sufficient.

The Fall. There is no danger of the grade of the tile being too great, and the only problem is to secure sufficient fall. A number of authorities on farm drainage and also several engineering manuals assert that a fall of 2½ or 3 inches per 100 feet is the lowest limit that should be attempted under the most favorable conditions; but practical experience has abundantly proved that a much smaller fall will give good drainage. In central Illinois and northern Indiana are many lines of tile having falls of only 1-6 to 1-4 of an inch per 100 feet which are giving satisfactory drainage; and not unfrequently the ordinary porous tiles laid absolutely level directly upon the earth in the bottom of the trench, without collars or other covering over the joints, have given good drainage without trouble from the deposit of sediment. Of course, extremely flat grades are less desirable than steeper ones, since larger tiles must be used, and greater care must be exercised in laying them, and there is more risk of the drain becoming obstructed; but these extremely flat grades are sometimes all that can be obtained, and such drains abundantly justify the expense of their construction.

If possible at reasonable expense, the grade should be at least 2 inches per 100 feet; and should never be less than ½ inch per 100 feet unless absolutely necessary. On level or nearly level ground, the fall may be increased by laying the tile at the upper end shallower than at the lower.

Laying the Tile. It is unwise to enter upon any detailed discussion of the art of laying the tile. The individual tiles should be laid in line both vertically and horizontally, with as small joints at the end as practicable. Care should also be taken that the tile is laid to a true grade, particularly if the fall is small, for if there is a sag it will become filled with sediment, or if there is a crest silt will be deposited just above it. The drain should have a free and adequate outlet. The end of the line of tile should be protected by masonry, by plank nailed to posts, or by replacing three or four tiles at the lower end by an iron pipe or by a wooden box.

The prevailing prices for laying tile in loam with clay subsoil is about as follows: for 8-inch tile or less 10 cents per rod for each foot of depth; for 9-inch, 11 cents; for 12-inch, 14 cents; for 15-inch, 17 cents; and for 16-inch, 18 cents. To aid in remembering the above data, notice that the price is 10 cents per rod per foot of depth for 8-inch tile or less, with an increase of 1 cent for each additional inch of diameter.

The cost of a mile of 5-inch tile drain is usually from $200 to $250, exclusive of freight on the tile. If there is any considerable amount of work, the above prices for the smaller tile can be reduced 10 to 20 per cent. A tile drain is a permanent improvement with no expense for maintenance, the benefit being immediate and certain; and therefore it is doubtful if money can be spent on earth roads to better advantage than in laying tile.

One or Two Lines? Usually a line of tile 2½ to 3 feet deep under the ditch at one side of the road will give sufficient drainage. Some tests made by the Illinois Agricultural Experiment Station (not yet published) seem to indicate that one line will give fairly good drainage under the most adverse conditions. The experiment consisted in the drainage of a piece of land selected as the worst that could be found in a part of the state notorious as having a large area of hard-pan which it was generally considered could not be underdrained "because the soil held water like a jug." Lines of tile were laid 2½ feet deep and 50 feet apart. The water level

at a point midway between the lines of tiles was lowered 18 inches, when at the same time the water level in the undrained portion of the field was only 6 inches below the surface. In this case the surface of the ground water had a slope of 1 foot in 25 feet.

A few other observations seem to confirm the above result for the slope of the surface of saturation in a retentive soil. The exact form of the surface of saturation is not known, but it is known to be a curve slightly convex upward. The inclination varies with the nature of the soil, is most convex near the tile, and is most convex immediately after a rain and gradually thereafter approaches an inclined plane.

The traveled portion is usually not more than 50 feet wide, and therefore a single line of tile 2½ to 3 feet below the bottom of the side ditch, if of adequate size, will give nearly perfect drainage; and a second line will not greatly improve it. For example, in Fig. 1, if A represents the first line of tile, the surface of the ground water is represented by the lines A B C.

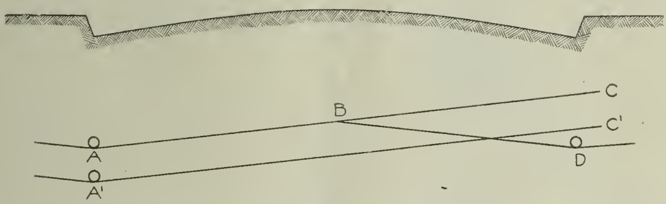

Fig. 1. Relative Effect of One Line and of Two Lines of Tile.

If a second line of tile, D, is laid, the water surface will be A B D, and the second line will drain only the comparatively small portion C B D. The diagram shows that a single line well below the surface is far better than two shallow ones. For example, lowering the tile A 6 inches, lowers the water surface to A′C′, which represents better drainage than the line A B D with the two lines of tile.

It is generally conceded that for agricultural drainage it is sufficient to place the lines of tile 100 feet apart, provided they are of reasonable size and at sufficient depth. A tile will give agricultural drainage 50 feet on either side of it; that is, a tile under only one side ditch will give agricultural drainage of the traveled way. More thorough drainage is required for agricultural

than for road purposes, since when damp most soils will pack, which is harmful to agricultural land but beneficial to a road.

The above seems to prove that one line of tile, if of proper size and at sufficient depth, will afford sufficient drainage for road purposes; but nevertheless it is claimed by competent authorities that two lines are sometimes required. In some localities a stratum of hard-pan near the surface makes it necessary to lay the tile so shallow that two lines are really required; and sometimes the tile is so small or so poorly laid that one line is insufficient.

In case of doubt as to whether one or two lines of tile are needed, put in one and watch the results. If both sides of the road are equally good, another tile drain is not needed. In making these observations care should be taken not to overlook any of the factors, as, for example, the difference in the effect of the sun upon the south and the north sides of the road, the effect of shade or of seepage water, the transverse slopes of the surface of the road, etc.

Location of the Tile. Some writers on roads recommend a line of tile under the middle of the traveled portion. A tile under the middle of the road is a little more effective than one at the same level under the side ditch; but the former is considerably more expensive to lay, since it necessitates more digging—whether the tile is laid before or after the road is graded. With the same depth of digging, a tile under the side ditch is more effective than one under the center of the road. Further, if the tile is under the center, there is liability of the settling of the soil in the trench, which will make a depression and probably a mud hole; and if the tile becomes stopped, it is expensive to dig it up, and the doing so interferes with traffic. Finally, if the road is ever graveled or macadamized, the disadvantage of having the tile drain under the center of the road is materially increased.

Some writers advocate the use of a line of tile near the surface, on each side of the trackway. The object of placing the tile in this position is to secure a rapid drainage of the surface; but very little, if any, water from the surface will ever reach a tile so placed, since the road surface when wet is puddled by the traffic, which prevents the water percolating through the soil. It is certain that in clay or loam the drainage thus obtained is of no practical value. Many farmers have tried to drain their barn-yard by laying

tile near the surface, but always without appreciable effect. The deeper the tile the better the drainage.

While a line of tile on one side of the road is usually sufficient, there is often a great difference as to the side on which it should be laid. If one side of the road is higher than the other, the tile should be on the high side to intercept the ground water flowing down the slope under the surface. Sometimes a piece of road is wet because of a spring in the vicinity, or perhaps the road is muddy because of a stratum which brings the water to the road from higher ground; in either case, the source of supply should be tapped with a line of tile instead of trying to improve the road by piling up earth.

II. Side Ditches.

The side ditches are to receive the water from the surface of the traveled way, and should carry it rapidly and entirely away from the roadside. They are useful, also, to intercept and carry off water that would otherwise flow from the side hills upon the road. Ordinarily they need not be deep; but, if possible, should have a broad, flaring side toward the traveled way, to prevent accident if a vehicle should be crowded to the extreme side of the roadway. The outside bank should be flat enough to prevent caving—an important matter which is frequently neglected.

If the road is tiled as previously recommended, the side ditch need not be very large; but it should be of such a form as to permit its construction with the "road machine" or scraping grader, or with a drag scraper, instead of requiring to be made by hand. On comparatively level ground, the proper form of side ditch is readily and cheaply made with the usual "road machine." An example of this form of ditch is shown in Fig. 2.

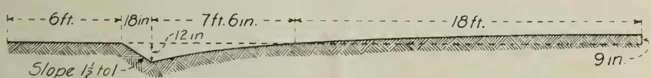

Fig. 2. Proper Form of Shallow Side Ditch.

If a larger and deeper ditch than shown in Fig. 2 is required, it can still be made chiefly and cheaply with the drag-scoop scraper. For an example of a deep ditch of this form, see Fig. 3, page 14.

A deep narrow ditch is expensive to construct, and also expensive to maintain, since it is easily obstructed by the caving banks, by weeds, and by floating trash. Fortunately the shallow ditch is easy and cheap to construct and also to maintain. If it is necessary to carry water along the side of the road through a rise in the ground, it is much better to lay a line of tile and nearly fill the ditch than to attempt to maintain a narrow deep ditch. A tile is very much more effective per unit of cross section than most open ditches.

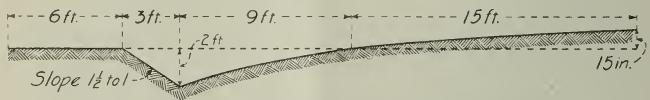

Fig. 3. Proper Form of Deeper Side Ditch.

The side ditch should have a uniform grade and a free outlet into some stream, so as to carry the water entirely away from the road. No good road can be obtained with side ditches that hold the water until it evaporates. Much ostensible road work is a positive damage for this reason. Piling up the earth in the middle of the road is perhaps in itself well enough, but leaving undrained holes at the side probably more than counterbalances the benefits of the embankment. A road between long artificial ponds is always an inferior one, and is often impassable. It is cheaper and better to make a lower embankment, and to drain thoroughly the holes at the side of the road. Public funds can often be more wisely used in making ditches in adjoining private lands than in making ponds at the roadside in an attempt to improve the road by raising the surface. It is cheaper and better to allow the water to run away from the road than to try to lift the road out of the water.

When the road is in an excavation, great care should be taken that a ditch is provided on each side to carry away the water so that it shall not run down the middle of the road. Every road should have side ditches, even one that runs straight down the side of a hill. Indeed, the steepest road needs the side ditch most, although it often has none. Frequently the water runs down the middle of the road on a side hill and wears it into gullies, which are a discomfort, and often dangerous, in both wet weather and dry.

In a slightly rolling country, the side ditch frequently has no outlet, and the water is allowed to accumulate at the foot of the

slope and there remain until it is absorbed by the ground or seeps into a tile drain. Under such conditions, the water seeps away very slowly, since the fine silt washed down from above forms an almost impervious coating which practically prevents any water from percolating through. The difficulty could be remedied by providing an inlet from the open ditch to the tile. This may be a well, walled with plank or masonry without mortar (except near the top) and having a grating in the side or top through which the water may pass. The well should be large enough to allow a man to enter it to clean it, and should extend a foot or more below the bottom of the tile. Earth roads in villages and towns are usually better provided with such inlets than country roads, but both could be materially improved at comparatively small expense by attention to this matter.

If it can be prevented, no attempt should be made to carry water long distances in side ditches; for large bodies of water are hard to handle, and are liable to become very destructive. Side ditches should discharge frequently into natural water-courses, though to compass this, it may in some cases be necessary to carry the water from the high side to the low side of the road. This is sometimes done by digging a gutter or by building a dam diagonally across the road, but both are very objectionable. A better way is to lay a tile or put in a culvert, the amount of water determining which shall be done.

It is sometimes necessary to carry water a considerable distance in the side ditches, as, for example, when the road is in excavation. This requires deep ditches, which are undesirable and dangerous; and if the grade is considerable, the ditches wash rapidly. In such cases, it is wise to lay in a line of tile under the side ditch, and turn the water from the surface ditch into the tile at intervals. This can be accomplished readily by inserting in the line of porous tile a Y section of vitrified sewer pipe, with the short arm opening up hill. Of course, the short arm, i. e., the vertical arm, need not be as large as the body. If necessary, two or three lengths of porous tile may be added at the upper end of the Y to make connection with the bottom of the open ditch. Earth, sods, or stones can be piled around the upper end of the tile to make a dam and to hold the tile in place.

As a rule, side ditches will not have too much fall, but sometimes a ditch straight down a hill will have so much fall as to wash rapidly, in which case it is an advantage to put in an obstruction of stone or brush. In extreme cases the bottom of the ditch is paved with stones.

III. Surface Drainage.

The surface drainage of a road is provided for by making the traveled way crowning and keeping it smooth. The making of the road crowning in the beginning is a matter of construction, and the keeping of the surface smooth is a question of maintenance. It should be remembered that water upon the surface of the road can not be carried away by the underdrains until after it has penetrated and softened the road surface.

Constructing the Crown. The slope from the center to the side should be enough to carry the water freely and quickly to the side ditch; and if the surface is kept free from ruts and holes, less crown will suffice than if no attention is given to keeping the surface smooth. If there is not enough crown, the water can not easily reach the side ditches; and hence the road soon becomes water soaked.

On the other hand, the crown may be too great. If the side slopes are so steep that traffic keeps continually in the middle, the road will be worn hollow and retain the water instead of shedding it promptly to the side ditches. With the ordinary method of caring for earth roads, more water stands on a very convex road than on a flatter one. If the crown is too great, it is difficult for vehicles to turn out in passing each other. Again, if the earth is piled too high in the middle, the side slopes will be washed into the side ditches, which not only damages the road but also fills up the ditches. Further, if the side slopes are steep, the top of the wheel will be farther from the center of the road than the bottom, and the mud picked up by the bottom of the wheel will be carried to the top of the wheel and then dropped farther from the center of the road than it was before, each vehicle acting like a plow and moving the earth from the center toward the side of the road.

The slope from the center to the side should be at least half an inch to a foot, or 1 foot in 24 feet; and it should not be more than 1 inch to a foot, or 1 foot in 12 feet. If the surface is well

cared for, the former is better than the latter; but in no case is it wise to exceed the latter slope. For a diagram showing a cross section of a road having the first named slope, see Fig. 2, page 13, and for the cross section of a road having the second slope, see **Fig. 3,** page 14; and for a road on an embankment, see Fig. 4.

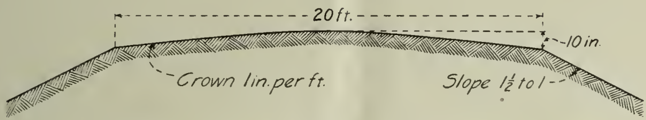

Fig. 4. Proper Crown for Road on Embankment.

The crown should be greater on steep grades than on the more level portions, since on the grade the line of steepest descent is not perpendicular to the length of the road, and consequently the water in getting from the center of the road to the side ditches travels obliquely down the road. If the water once commences to run down the center of the roadway on a steep grade, the wheel tracks are quickly deepened, stones are loosened or uncovered, and the road becomes rough and even dangerous. Under these circumstances, it is necessary to construct catch-waters, "water-breaks," "hummocks," or "thank-you-marms" at intervals to catch the water which runs longitudinally down the road, and convey it to the side ditches, thereby preventing the formation of gullies in the road surface. These catch-waters may be either broad shallow ditches or low flat ridges constructed across the road; and they may slope toward one or both ditches. In the former case, they should cross the road diagonally in a straight line; and in the latter case, in plan they should be a broad angle with the apex at the center of the road pointing up hill. There is little or no difference between the merits of the ditch and the ridge, unless the bottom of the former is paved with gravel, broken stone, or cobbles. The ridges are more common, but usually are so narrow and so high as to form a serious obstruction to traffic. However, neither the ditches nor the ridges should be used except on steep grades where really necessary, since either form is at best an obstruction to travel. The angle that the catch-waters shall have with the axis of the road should be governed by the steepness of the grade—the steeper the grade the more nearly should the catch-waters run down the road. They should have a considerable

breadth so that wheels may easily ascend them and horses will not stumble over them.

Catch-waters should also be constructed in a depression where an ascending and a descending grade meet, in order that they may collect the water that runs down the traveled way and convey it into the side ditches. These catch-waters should run square across the road, and should be quite shallow ditches, the bottom of which is hardened with gravel, broken stone, or cobbles.

Some writers recommend that a surface of the road on the face of hillsides should consist of a single slope inclining inwards. This form of surface is advisable on sharp curves, but is of doubtful propriety elsewhere. The only advantage of this form is that the water from the road is prevented from flowing down the outer face of the embankment; but the amount of rain water falling upon one half of the road can not have a very serious effect upon the side of the embankment. With a roadway raised in the center and the water draining off to either side, the drainage will be more effectual and speedy than if the drainage of the outer half must pass over the inner half. If the surface is formed of one plane, the lower half of it will receive the greater share of the travel; and as it will be more poorly drained, it is nearly certain to wear hollow. This will interfere with the surface drainage; and consequently a road with this section will require excessive attention to keep it in good condition.

Whatever the form of the road surface, if the hillside is steep there should be a catch-water above the road to prevent the water from the hillside above from flowing down on the road. It should be, say, 6 feet back from the excavation, and should have a width and depth according to the amount of water to be intercepted.

Maintaining the Crown. Proper maintenance is as important as good construction. A distinction should be made between maintenance and repairing. The former keeps the road always in good condition; the latter makes it so only occasionally. If the road is not properly maintained, it deteriorates in a geometrical ratio—a small depression fills with water and soon becomes a mud hole which traffic makes deeper and deeper, or an obstructed side ditch forces the water to run down the center of the road and gullies

out the surface. A defect which could be remedied in the beginning with a shovelful of earth or a minute's time, if neglected may require a wagon load of earth or an hour's time, besides being in the meantime an annoyance or a danger to traffic. The better the state in which the road is kept, the less are the injuries to it by ordinary traffic and the weather.

Water is the natural enemy of good earth roads. The chief object of maintenance should be to keep the surface smooth and properly crowned so that rain water will be shed promptly into the side ditches. These should be kept open so that the water may be carried entirely away from the road.

Smoothing the Surface. The most important work in maintaining an earth road is to keep the surface smooth so that the rain water will flow quickly in to the side ditches. If the surface of the roadway is properly formed and kept smooth, the water will be shed into the side ditches and do comparatively little harm; but if it remains upon the surface, it will be absorbed and convert the road into mud. If all ruts, depressions, and mud holes are not filled as soon as they appear, they will retain the water upon the surface, to be removed only by gradually soaking into the road-bed and by slowly evaporating; and each passing wheel or hoof will help to destroy the road.

There are several machines or devices which are very effective in filling ruts and depressions, and in keeping the surface smooth. The different tools are best under different conditions.

Harrow. In the winter there frequently come times when the road is full of holes and ruts, while the surface soil is dry and mellow. This condition occurs most frequently when the ground below the surface is frozen. If at this time a harrow is run over the road, it will fill up the ruts and holes and leave the surface comparatively smooth. This improves the road for present travel, and gives a smooth surface which will greatly decrease the deterioration of the road by subsequent rains. The ordinary adjustable farm harrow should be used, and the teeth should be set to slope well back. The labor required is not great, since a 12-foot harrow can be used, and then a single round is sufficient.

Often there are only a few hours in the middle of the day when the frost is out of the ground sufficiently to permit this work to be done, and therefore it is best for each farmer to harrow the road adjoining his own land. The work comes at a season of the year when the farmer's time is usually not very valuable, and hence the expense is small. This method of treating earth roads has proved very beneficial both in securing good roads and in preserving them.

In the summer, when the roads get roughed up, they can be materially improved at small expense by running over them with a harrow having the teeth down quite flat. If the roads are a little muddy, this treatment will make them dry faster and also make them much more pleasant to use after they have dried.

Railroad Rail. In the early spring, just after the frost goes out of the ground, earth roads are usually full of deep ruts. The harrow is not suitable for the work now required. The object is simply to cut off the ridges and fill up the ruts, and thus "break the way" for travel. It is well to break the road early in the season, both to accommodate immediate travel and to hasten the coming of a better condition of the road. It is much more economical to make the road smooth with a railroad rail or its equivalent than to wear it down by travel.

A railroad rail 14 to 16 feet long drawn by two two-horse teams has been used with great success in breaking down the ridges and filling up the ruts. The team is hitched to an eye fastened through the web 2 or 3 feet from the end of the rail. The edge of the base of the rail serves as a cutting edge. A 7-inch steel I-beam is equally good.

When the ground is mellow and loose after freezing and thawing, the steel rail will smooth the road nearly as satisfactorily as the "road machine," or scraping grader, as it is more properly called, and much more rapidly, since it cuts a wider swath and since the draft is so light that the teams walk right along. One round trip is usually sufficient for any road. The time when the work is most advantageously done is comparatively limited; and therefore one rail should not be expected to cover too much road. The cost is so small that one can be provided for each few miles of road—the number depending upon the climate and the nature of the soil. If roads are treated in this way, they will not get so rough; and hence will require less work later with the heavy road machine.

Light Scraper. A heavy stick of timber, say, 6 x 12 inches, faced on one side with a steel plate, and drawn by a team, is very effective in smoothing the way for travel. To the top face of the timber should be fastened a frame by which to hitch the team. This frame should be in the form of a capital A with one leg a little shorter than the other, to cause the cutting edge to stand obliquely to the line of draft. The blade should be about ¼ inch thick, 4 inches wide, and as long as the timber, say 6 or 7 feet.

There are many "road machines" on the market, all of which are most excellent for certain kinds of work, but most of which are too heavy for the conditions just described. Most of the machines are mounted upon four wheels, and of themselves are a considerable load over roads which are only a succession of ridges, ruts, and mud holes; and are heavier and more cumbersome than is necessary for the work now under consideration.

Split-Log Drag. Fig 5 shows a form of road drag first made by Mr. D. Ward King, of Missouri. The main pieces are the two halves of a log 10 or 12 inches in diameter and 7 to 9 feet long.

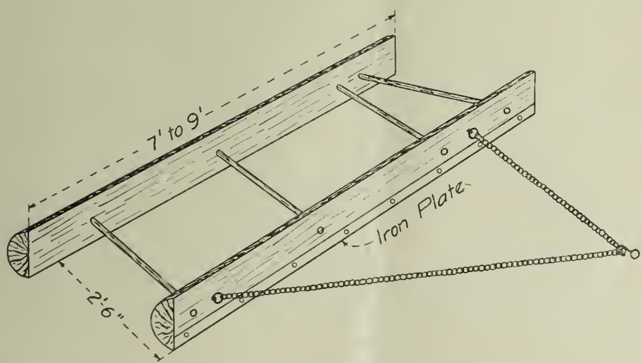

FIG. 5. THE KING SPLIT-LOG ROAD DRAG.

The log should be some light wood, as oak is too heavy. The cross sticks should be about 30 inches long. The ring or hook to which the double-trees are attached should be about 2 or 2½ feet in front of the drag. The two pieces of the chain should have such lengths that the log will stand at an angle of about 45° with the direction the team travels. The lower edge of the front slab should preferably be protected by a steel plate ¼ inch thick and 3 or 4 inches

wide. A wide plank should be laid upon the connecting sticks, upon which the driver may stand.

A drag similiar to that shown in Fig. 5 may be made of a 2-inch by 10-inch or a 3-inch by 12-inch plank instead of the two halves of a split log. Mr. King deserves credit for the intelligence and persistency with which he has advocated the use of the drag in keeping smooth the surface of an earth road. If the surface of the road is kept smooth, the rain water is speedily drained into the side ditches and besides the road is always pleasant to drive upon.